2017-07-10

INVESTIGATION OF RELATIONSHIPS BETWEEN CHANGES IN EEG FEATURES AND SUBJECTIVE QUALITY OF HDR IMAGES

Al-Juboori, S::0000-0001-5175-736X

10.1109/icme.2017.8019544
2017 IEEE INTERNATIONAL CONFERENCE ON MULTIMEDIA AND EXPO (ICME)
IEEE

INVESTIGATION OF RELATIONSHIPS BETWEEN CHANGES IN EEG FEATURES AND SUBJECTIVE QUALITY OF HDR IMAGES

Shaymaa Al-Juboori, Is-Haka Mkwawa, Lingfen Sun and Emmanuel Ifeachor
Signal Processing and Multimedia Communication
Plymouth University, UK
E-mail: {shaymaa.al-juboori, is-haka.mkwawa, l.sun, e.ifeachor}@plymouth.ac.uk

ABSTRACT

Quality of Experience (QoE) assessment of multimedia services is a challenging task and an understanding of how the user perceives quality at the physiological level would facilitate this. Physiological signals, such as the electroencephalogram (EEG), have shown promise in revealing the subject's emotion or attention in quality assessment and the correlation of this with media service quality. This paper investigated the relationships between changes in EEG features and subjective quality test scores (i.e. MOS) for High Dynamic Range (HDR) images viewed with a mobile device. Results show that changes in the gamma and beta bands correlated negatively with MOS, whereas positive correlations were observed in the alpha band. Coupling between activities in the delta and beta bands (i.e. positive correlation between power in the fast beta and slow delta frequency bands) is related to anxiety and dissatisfaction. Thus, the results suggest that increases in the degree of coupling are associated with decreases in HDR quality. This also suggests that in the HDR image QoE assessment, human emotions play a significant role. Potentially, these findings may be exploited in objective QoE perception modelling.

Index Terms— High dynamic range images, quality of experience, electroencephalography, Mean Opinion Scores, delta-beta coupling, subjective tests.

1. INTRODUCTION

QoE is an important issue in various image and video applications. It is necessary to understand how humans perceive quality from visual stimuli as this can be potentially exploited for developing and optimizing images and video processing algorithms [1].

Recently, image consumption using mobile devices has become increasingly popular because of the availability of smartphones capable of producing and consuming HDR images and advances in high-speed wireless communication networks. One of the most critical issues in mobile HDR image delivery services is how to maximize the QoE of the users for the delivered contents. An open research question is how HDR images with different contents perform on mobile phones [2].

Traditionally, evaluation of perceived quality of multimedia content is done using subjective opinion tests, such as Mean Opinion Scores (MOS). However, it is difficult for the user to link the experienced quality to the quality scale. Moreover, MOS does not give an insight into how the user really feels, at the physiological level, in response to dislikes or satisfactions with the perceived quality [3].

To address this issue, measures which can be taken directly (implicitly) from the participant have attracted interest. The electroencephalogram (EEG) is a promising approach which may be used to assess quality related processes implicitly [2]. At present, there is no standard for using electrophysiology to assess QoE, but contributions are being made to the ITU-T on the use of physiological measures for QoE (e.g. ITU-T Contribution COM 12-(039, 112, 103, and 202). However, implicit QoE approaches are still in the early stages and further research is necessary to better understand the nature of the recorded neural signals and their associations with user-perceived quality from QoE perspectives [5].

We propose a novel electrophysiology-based QoE assessment approach for HDR image quality which may be used to predict perceived image quality. Previous studies [3] [6] [7] [10] have demonstrated that physiological measurements provide valuable insight into QoE of advanced media technologies. In our study, the correlation between the mean power in the delta and beta bands is used as a measure of the coupling between the activities in these bands. This is linked with negative behavioural characteristics (e.g. anxiety, frustration, dissatisfaction). Our study is based upon clinical findings [12-16] which suggest that increased EEG delta-beta coupling promotes behavioural inhibition states. Thus, increases in the degree of coupling are associated with decreases in HDR quality. This has not hitherto been used in electrophysiology-based QoE assessment for HDR image quality. This approach may provide an insight into human preferences and perceptions about a service or product and hence user-perceived quality. The specific objectives of the paper are:

- To investigate changes in brain activities during HDR image quality assessment.
- To understand the changes in the EEG which are related to HDR image quality perception in terms of QoE.
- To investigate the relationships between the coupling between delta and beta activities and the MOS.

We have used HDR imaging in the study as it has emerged as one of the most promising recent developments in multimedia technology and which has wide applications. 20 HDR images which have been processed by four different TMOs (Tone-

Mapped Operators) were viewed by 28 subjects on small screen devices (SSDs). The MOS scores were obtained and the EEG data recorded during the test. The relationships between MOS and EEG features were then investigated. Results show that changes in the gamma and beta bands correlated negatively with MOS, whereas positive correlations were observed in the alpha band. The beta band had the most significant association with ($P > 0.001$) MOS. Analysis of the results showed that EEG-based measures provided additional information in understanding human perception of contents.

The rest of the paper is organized as follows. In the next section, we describe the related work; in Section 3 details of the data collection are provided. Section 4 presents the analyses of the results of the subjective assessment and EEG measures. Finally, conclusion and future work are presented in Section 5.

2. RELATED WORK

2.1. Electroencephalography in HDR

There has not been much research regarding the evaluation of HDR image quality using EEG measurements. Often, the EEG is used in brain computer interface (BCI) applications, where it assists users in image classification tasks [9]. Hayashi et al [9] used the EEG to evaluate the quality of high resolution images, and found that images with good quality produced a higher amount of alpha activity than images with poor quality. Kroupi et al. [6] analysed the degradation of 2D and 3D videos using sequences from a music festival. They found that the EEG shows a high frontal asymmetry in the alpha power band, reflecting emotional affect towards the two different quality levels. Moon et al. [3] used four different HDR and LDR (low dynamic range) video contents. The power in the bands was extracted from the EEG data as features and used for classification. This gave an accuracy of almost 70% if only EEG features were used and almost 80% if other peripheral measures were used for classification as well. Moreover, gamma band gave the most discriminative results between conditions. The above studies focused only on one frequency band (e.g. alpha or gamma) and did not investigate in detail the association between the bands or the relationships with the QoE. Furthermore, previous studies all used sophisticated, hospital-grade, EEG devices in the lab environment which are not widely accessible for QoE assessment purposes. Few research studies have explored the potential of portable EEG devices for multimedia quality assessment. Moldovan et al. [7] used features provided by the Emotiv EPOC System to infer the level of frustration from the human observer caused by the quality of audio-visual excerpts. This level was based on a metric predefined by the headset manufacturer for different levels of video quality. The level of quality was controlled through changing the bitrate, frame rate as well as the resolution of the presented video clips. Perez et al. [10] used the Neuro-Sky Mind-Wave headset to measure brain activity and used the recorded data to classify the trials into high and low quality pictures. All the above studies were focused on voice/video quality, but not on HDR images.

2.2. Delta-beta coupling

Delta–beta coupling (positive correlation between power in the fast beta and slow delta frequency bands) has been related to affective processing [12-16]. For instance, differences in delta–beta coupling have been observed between subjects in a psychological stress condition and controls and have been linked with negative behavioural characteristics (anxiety, frustration, dissatisfaction). In Gray's theory [12], the authors suggested that delta–beta coupling appear only in a frustrating situation, that is, it should be state-dependent. Another important point is that for anxiety generation, there must be concurrent and equivalent activation of fear and approach systems. In Knyazev et.al [13], it is shown that the correlation between mid-frontal delta and beta spectral power increased in healthy male subjects with an increase in anxiety and behavioural inhibition. It has also been found that there is higher positive correlation between delta and beta powers in subjects with higher baseline level of salivary cortisol (the steroid hormone directly associated with anxiety) [14]. A hypothesis is that coupling reflects higher cortical arousal in frustrating situations [15]. It has also been found that coupling is very sensitive to external influences since it allowed detection between good and bad performance conditions [15].

3. DATA COLLECTION

In this study, explicit subjective tests and implicit tests using the EEG were conducted. The study involved several participants viewing and rating the quality of HDR images with different TMOs while their EEG data were recorded at the same time.

3.1. Participants

Twenty eight subjects including 13 female and 15 male (Mean= 30.6, SD= 3.890, age range of 25- 45 years old), all right-handed participated in the test. All subjects had normal or corrected vision and are non-experts in HDR. However, they all have a clear understanding of the test and are all postgraduate students. Before each experiment, a training session was given to allow participants to familiarize themselves with the procedure. The images used in the training session were different from the test stimuli. The study protocol was approved by the Research Ethics Committee at Plymouth University.

3.2. Tests Stimuli

Five HDR images were selected for the study, based on their visual content, quality, and the dynamic range. The five images were each processed by four TMOs, giving a total of 20 HDR images. The best four TMO from our previous study were used [11] *AL1: Adaptive Logarithmic*; this is a fast algorithm suitable for interactive applications which automatically produces realistically looking images for a wide variation of scenes exhibiting high dynamic range of luminance. *AL2: iCAM06*; this is based on the physiology of the human's eye photo-receptors. The output of the operator is a combination of a locally adapted value around each pixel of the image and a globally adapted value based on the image averages. *AL3: Photographic Reproduction*; this is based upon dodging-and-burning in traditional photography. It automatically applies various scales for luminance mapping to the prorated regions of highlights and shadows. *AL4: Bilateral Filtering;* this is fast bilateral filtering for the display of HDR images conserving local details in the image. The images used for the validation were computed using a MATLAB® HDR toolbox. The default settings of the operators' performance were used.

3.3. EEG signal acquisition

A portable EEG device (HeadCoach™, Alpha-Active Ltd, Devon, UK) [8] was used to record scalp electrical activity, with a sampling frequency 128 Hz, band-pass filter, 0.5-60 Hz, from two active (positive inputs) electrodes, placed at Fp1 and Fp2 according to the 10–20 EEG system [4]. Before the electrode placement, the skin was prepared with an abrasive skin preparation gel (Nuprep™, Weaver and Company, Aurora, USA) and then cleaned with alcohol-free wipe. The spectrum of the recorded is computed and the time and frequency domain data were stored in CSV format for subsequent analysis.

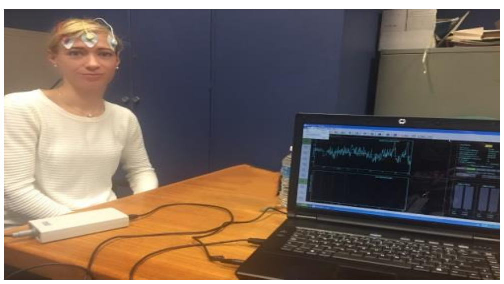


Fig.1. A participant preparation before the experiment

3.4. Test Setup

The set-up for the test is illustrated in Fig.1. An iPhone 6 device running on IOS operating system was used to display the HDR images. This has a 4.7-inch Retina HD display with resolution of 1334×750. An Intel Core™ i7 PC running Microsoft Windows 7 Enterprise operating system was used to process the EEG data. The iPhone and the EEG recording PC were time synchronized to facilitate the data analysis.

3.5. Test Methodology

The experiment consisted of two sessions. During each session, 10 stimuli were displayed on the device. Half an hour break was given between the two sessions to prevent lack of attention and fatigue and to ensure comfort. Each session lasted approximatively half an hour, excluding the training and the setup of the EEG devices. Each trial consisted of a 30-second baseline phase, an HDR stimulus period and a rating phase as shown in Fig.3. During the baseline period, subjects were instructed to remain calm and to focus on a 2D white cross on a grey background presented on the screen in front of them. The EEG signals recorded during the baseline period were used to remove stimulus-unrelated variations from the signals acquired during the stimulus period. Once the baseline period was over, an HDR image stimulus was presented for 30 seconds. At the end of this, subjects were asked to provide their ratings for the HDR image stimulus within 60 seconds. After the participant has submitted the rating, the next stimulus appears on the SSD, with the order of sessions and trials randomised. The test sequences and quality ratings were displayed on a web site. Subjects were asked to evaluate the HDR stimuli (see Fig.2). We chose a discrete five-level rating scale (ITU-R quality ratings [4]), which is suitable for naïve observers (non-experts in image processing) and is relatively easy for them to use it to quantify quality ('5=Excellent' and '1=Bad') [6]. Fig.3 illustrates an example of a test trial including baseline, stimuli, and rating period.

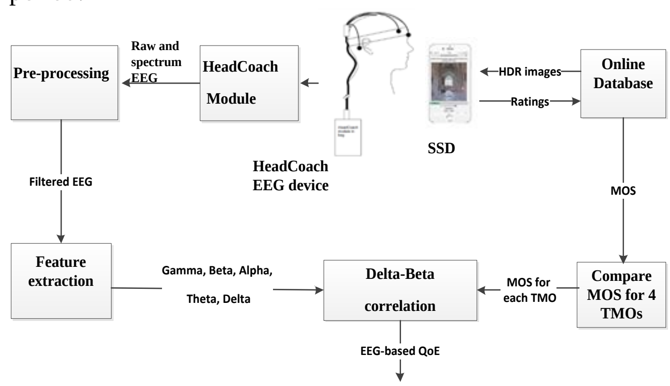


Fig.2. the test-bed for HDR image quality assessment

3.6. Pre-processing

For EEG analysis, the MATLAB toolbox EEGLAB was used. The recorded EEG signals was filtered using an IIR filter to extract the frequency bands of interest between 0.5-60Hz. Thirty-three seconds of data were recorded for each subject, but only the last 30 seconds of all signals were used in our analysis, considering that stabilization and adaptation to the HDR contents may take some time.

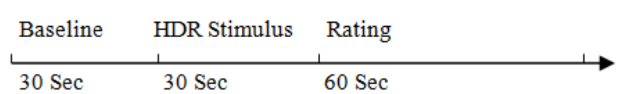


Fig.3 Trial timeline

3.7. Feature extraction

The baseline power was subtracted from the trial power, yielding the change in power relative to the pre-stimulus period. These changes in power were averaged over the frequency bands, namely delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), band (13–30 Hz) and gamma (30–60 Hz) frequency bands, for each channel. Delta activity is present during sleep and continuous attention; theta activity occurs during light sleep and provides an indicator for decreased alertness and for encoding new information. Activity in the alpha band is related to alertness and good quality images and is a function of age. Beta activity is related to cognitive thinking and visual attention and is significantly increased in 3D environment. Finally, gamma band is related to visual information process, brain activity and good quality image [9].

4. RESULTS DISCUSSION

4.1. Subjective rating analysis

In this section, the results of subjective rating are described with the aim of providing an understanding of the characteristics of QoE of tone mapped HDR images and factors that affect QoE. The first step was to detect and remove outliers in the subject MOS results so that they do not influence the results. Outlier detection procedure was applied to the results obtained from the 28 subjects and performed according to the guidelines described in Section 2.3.1 of Annex 2 of ITU-R BT.500-13 [5]. MOS representing the average subjective quality ratings across all participants are usually represented on nominal scales and associated 95% Confidence Interval (CI) were presented for the four quality levels algorithms as recommended in [5]. Fig.4 is the average MOS for *AL1*, *AL2*, *AL3* and *AL4* respectively; Bilateral Filtering AL4 had the best performance from the observers' point of view.

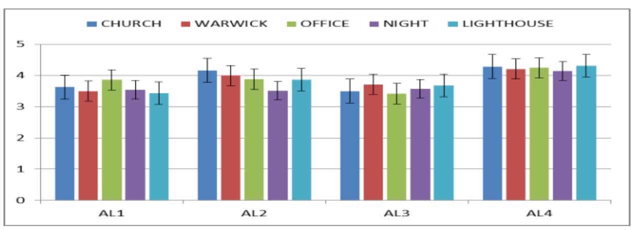
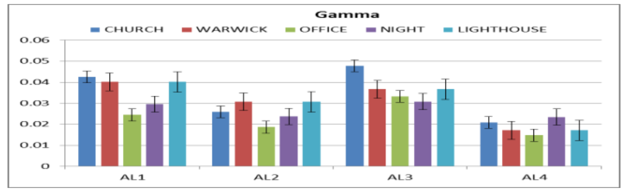


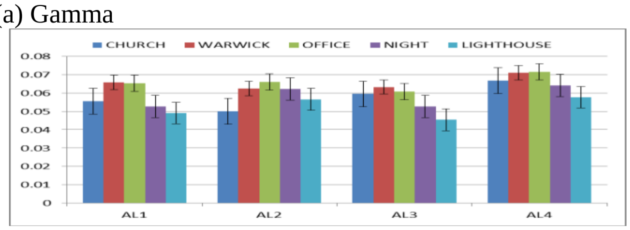
Fig.4. MOS and CIs for experienced TMOs

4.2. EEG signal analysis

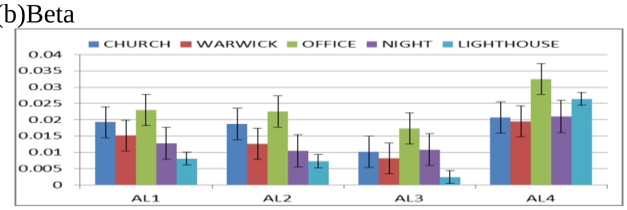
It is known that high gamma power corresponds to high brain activity and that the brain is highly activated when the perceived quality is low. This indicates that perception of low quality is related to negative emotions [2] [8] [10] [16]. It also implies that higher gamma means lower quality for HDR image (Fig.5.a). AL4 gave the lowest results, which indicates that it has the highest quality. In accordance with [18-20], we also found significantly higher beta for positive emotional tasks (high perceived HDR quality in our case) compared to other frequency bands results. Therefore, cognitive and emotional processes seem to take place during quality perception of HDR images. From the beta results, Fig.5.b, there is no large variance in the mean power level. This suggests that the brain reacted cognitively and emotionally with the HDR images in the same way. Furthermore, high alpha power indicates brain activation when overall perceived quality is high, whereas alpha power in brain is deactivation when overall perceived quality is low [3] [6] [9-10]. In Fig.4.c, *AL4* gave the highest Alpha result, i.e. best perceived quality. In the theta frequency band, Fig.4.d, EEG power is negatively related to cognitive performance and brain maturity, theta synchronization is positively correlated with the ability to encode new information [16]. From the results, we can see that theta mean power amplitude is very low (~10^{-5}) compared with all other frequencies, which is an indicator for increasing alertness [16].



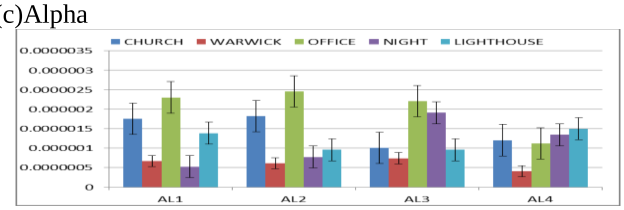
(a) Gamma



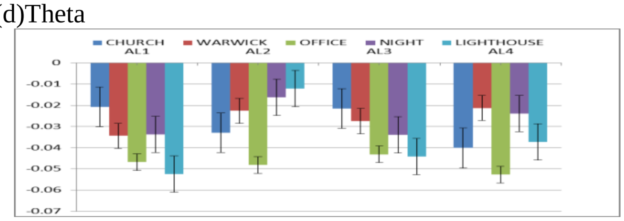
(b)Beta



(c)Alpha



(d)Theta



(e) Delta

Fig.5. Mean power for (a) Delta (b) Theta (c) Alpha (d) Beta and (e) Gamma

4.3. Correlation and Analysis of Variance

To estimate the correlation between changes in the EEG and subjective scores, the mean of all power in the frequency band across subjects were calculated. The Pearson linear Correlation Coefficient was calculated between the mean power values and the MOS for subjective ratings, per frequency bands (see Table 1). From Table 1 we can see that the highest correlation is between MOS and gamma frequency band [2] [10], but this is negatively correlated; Thus, higher gamma means lower quality for HDR image. The *AL4* TMO gave highest correlation.

The results also show that Alpha is positively correlated with MOS and that AL4 gave the highest c The correlation values for beta band, however, were not high but they followed the hypothesized inverse relationship trend. This is probably because the subject's judgement may not always follow the objective neurophysiological facts. Additionally, it is likely due to neutrality of the content utilized for the HDR stimuli, which may not have evoked strong enough emotional characteristics [3] [6-7]. Theta and Delta correlate positively, but the correlation is weak.

Table 1. Pearson correlation between MOS and the frequency oscillations for each algorithm (quality)

	AL1	AL2	AL3	AL4
Gamma	-0.6605	-0.8132	-0.5660	**-0.8747**
Beta	-0.6005	-0.6492	-0.6012	**-0.6820**
Alpha	0.5320	0.7523	0.5004	**0.7830**
Theta	0.2648	0.2592	**0.3336**	-0.1039
Delta	0.0637	**0.2211**	0.0477	0.0814

The Spearman correlations were estimated between the mean powers values for each frequency band and the subjective ratings, for all image contents (seeTable.2). We found significantly higher beta in *Night* and *Lighthouse* compared to *Church, Warwick* and *office* for positive emotional tasks (preferred content in our case). Hence, cognitive and emotional processes seem to take place during quality perception of HDR image. An increase in alpha and theta level is the result of a reduction in quality. This increase may be due to an increased the level of anxiety, fatigue and drowsiness [17-20]. We found significantly lower alpha and theta in *Night* and *Lighthouse* compared to *Church, Warwick* and *Office*. This finding implies that subjects in this study rated perceived quality by taking into account how pleasant or annoying the content was. Moreover, high gamma power corresponds to high brain activity and suggesting that the brain is highly activated when perceived quality is low [20].

Table 2. Pearson correlation between MOS and the frequency oscillations for each content.

	Church	Warwick	Office	Night	Lighthouse
Gamma	-0.7301	-0.7971	-0.808	-0.362	-0.4675
Beta	-0.5632	-0.4345	-0.443	-0.739	-0.8091
Alpha	0.5857	0.4155	0.6622	0.1765	0.1144
Theta	0.4328	0.4774	0.5769	0.1976	0.1649
Delta	0.1264	0.1109	0.0846	0.0109	0.0116

We found significantly lower gamma in *Night* and *Lighthouse* compared to *Church*, *Warwick* and *office*; this indicates that low perception of quality is related to negative emotions. Methodologically, our results indicate that Theta and Alpha frequency bands offer a means of studying cortical activation patterns during both cognitive and emotional information processing.

To investigate quantitatively whether the HDR image quality has a significant influence on the EEG frequency bands, an ANOVA analysis was performed on the subjective ratings, with a significance P-value threshold of 0.001. Table 3 summarizes the ANOVA results and beta gave a significant P-value < 0.001. Overall, the results from the ANOVA analysis revealed that beta has an impact on HDR perceived quality. However, the other interactions were not significant, P > 0.001. It has been established that beta band is highly associated with cognition thinking, and reflects emotional behaviour [16]. Our finding parallels that of Kroupi et al [6] which found that beta frequency band significantly increased in the 3D environment, which received a significantly higher score in comparison to 2D video.

Table 3. ANOVA analysis

Source	dF	F	P-value
Delta	3	5.092	0.001668
Theta	3	5.342	0.001178
Alpha	3	5.356	0.001155
Beta	3	5.470	**0.000984**
Gamma	3	5.292	0.001263

4.4. The coupling measurments

To understand human behavioural states at the neural level, the coupling between delta and beta frequency bands was computed as the correlation coefficient between the mean powers in the frequency bands. This is linked with negative behavioural characteristics (anxiety, frustration, dissatisfaction). Clinical literature [12-15] indicates that increased EEG delta-beta coupling promotes behavioural inhibition states. This means that the closer the coupling (or correlation) is to 0, the more the subject would be satisfied with the test. On the other hand, as coupling or correlation approaches 1, the less the subjects like the HDR image (or the more frustrated they are frustrated by the test). By calculating the coupling values between delta and beta for each tone-mapped HDR image quality from the results, high coupling values (e.g. greater than 0.5) would be considered to represent unsatisfied subjects (or subjects who had an unpleasant experience).

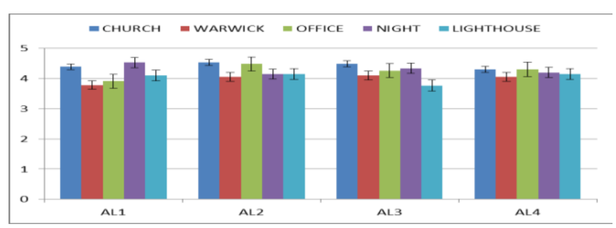


Fig.6. MOS and CIs for experienced TMOs after coupling

To explore this point, the scores for subjects who were unsatisfied were removed (7 out of 28) from the dataset. Fig.6 shows the MOS for the four quality levels for the five contents after removing those subjects. By comparing Fig.4 and Fig.6, we can see the MOS values per algorithm per content have increased. On the other hand, the Standard deviation and 95% confidence interval have decreased. The results suggest that it is sometimes difficult for participants to link the experienced quality to the quality scale in explicit tests and that EEG-based measure provides additional and complementary information which aids understanding of human perception of contents.

5. CONCLUSION

This paper investigated the relationships between changes in EEG features and a QoE metric (i.e. MOS) for HDR images. 20 HDR images were viewed by 28 subjects during informal subjective tests and the subjects' EEG data were also recorded and subsequently processed. To investigate quantitatively whether the HDR image quality has a significant influence on the EEG frequency bands, an ANOVA and Pearson correlation analysis were performed on the subjective ratings. We found that gamma, beta, and delta frequency bands gave the most discriminative correlation with MOS. Moreover, from the ANOVA results, beta band gave a significant p-value < 0.001. Overall, the results from the ANOVA analysis revealed that changes in the beta had an impact on HDR perceived quality. The present results indicate that induced emotions have visible electrophysiological correlates with the content. Emotional activation paradigms in association with electrophysiological measures represent a fruitful experimental avenue for future research in illustrating the biological correlates of emotions. In future, we will increase dataset used and investigate further the role of the delta- beta coupling coefficient in quality assessment and its implications for QoE assessment.

6. REFERENCES

[1] M. Narwaria, et.al. "High dynamic range visual quality of experience measurement: Challenges and perspectives", Visual Signal Quality Assessment, Springer International Publishing, pp. 129-155, 2015

[2] M.Melo, M. Bessa, K. Debattista and A.Chalmers, "Evaluation of HDR video tone mapping for mobile devices. *Signal Processing: Image Communication*, *29*, 2 (February 2014), 247–256

[3] S.E. Moon and J.S. Lee. "Perceptual experience analysis for tone-mapped HDR videos based on EEG and peripheral physiological signals". IEEE Transactions on Autonomous Mental Development, 7(3), pp.236-247. 2015

[4] A. H. Al-nuaimi, E. Jammeh, L. Sun and E. Ifeachor, "Changes in the EEG amplitude as a biomarker for early detection of Alzheimer's disease," 2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Orlando, FL, 2016, pp. 993-996, EMBC.2016

[5] ITU, Methodology for the subjective assessment of the quality of television pictures, Recommendation BT.500-13 2010.

[6] E. Kroupi, P. Hanhart, J.S. Lee, M. Rerabek and T. Ebrahimi.", September. EEG correlates during video quality perception". In 2014 22nd European Signal Processing Conference (EUSIPCO), 2014.

[7] A.-N. Moldovan, I. Ghergulescu, S. Weibelzahl, and C.H. Muntean, "User-centered EEG-based Multimedia Quality Assessment," in Proc. International Symposium on Broadband Multimedia Systems Broadcasting, 2013.

[8] Alpha-Active Ltd. [Online]. Available. http://www.alpha-active.com/

[9] S. Arndt et.al." Review on using physiology in quality of experience. Electronic Imaging", 2016(16), pp.1-9.

[10] J. Perez and E. Del´echelle, "On the measurement of image quality perception using frontal EEG analysis," in International Conference on Smart Communications in Network Technologies, 2013

[11] Sh.Al-juboori, I.Makwawa, L.Sun and E.Ifeachor." Impact of Tone-mapping Operators and Viewing Devices on Visual Quality of Experience" in proceeding of IEEE ICC 2016.

[12] J.A. Gray, N. McNaughton," The Neuropsychology of Anxiety: An Enquiry into the Functions of the Septo-Hippocampal System" (2nd ed.)Oxford University Press, Oxford, 2000

[13] G.G. Knyazev, A.N. Savostyanov, E.A Levin." Alpha oscillations as a correlate of trait anxiety". Int. J. Psychophysiol. 53, 147–160. 2004

[14] D.J.L.G. Schutter and J.V. Honk, "Salivary cortisol levels and the coupling of midfrontal delta–beta oscillations," Int. J. Psychophysiol., vol. 55, pp. 127129, 2005.

[15] G.G. Knyazev, D.J.L.G. Schutter, and J. V. Honk, "Anxious apprehension increases coupling of delta and beta oscillations," International Journal of Psychophysiology, vol. 61, no. 2, pp. 283 – 287, 2006.

[16] R. Gupta, et.al. "Objective characterization of human behavioural characteristics for QoE assessment: A pilot study on the use of electroencephalography features". In 2013 IEEE Globecom Workshops (GC Wkshps) (pp. 1168-1173). IEEE.2013.

[17] W. J. Ray and H. W. Cole, "EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes," Science, vol. 228, no. 4700, pp. 750–752, 1985.

[18] W. Klimesch, "Alpha-band oscillations, attention, and controlled access to stored information". Trends in cognitive sciences. 2012 Dec 31;16 (12):606-17.

[19] N.Rowland, MJ. Meile, S. Nicolaidis," EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes". Science. 1985; 228 (4700):750-2.

[20] MM. Müller, A. Keil, T. Gruber, T. Elbert "Processing of affective pictures modulates right-hemispheric gamma band EEG activity". Clinical Neurophysiology. 1999 Nov 1; 110 (11):1913-20.